# SYSTEM LEVEL OPTIMIZATION THROUGH THE USE OF STATISTICAL SIMULATION

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## Introduction

A critical issue in the optimization of systems is that of the design of the part, component or system for manufacture. The system engineering function typically finds an acceptable but theoretical design solution with little up-front attention being paid to the "real-world" effects caused by manufacturing and operational variabilities. Alternatively when system design attention is paid to such variabilities, it is usually via a "worst-case" design process which can only further complicate the manufacturing process and raise costs. To be truly effective in the near future of small-lot flexible system manufacturing, systems engineering must not only optimize against the effects of changing manufacturing variabilities, but the overall systems design and manufacturing processes must be woven more closely together so as to permit routine first pass success [l].

As a result of the above issues, the importance of running early statistically based system level design simulations has become particularly critical in this period of increasingly flexible manufacturing processes, defense conversions and dual-use technologies.

## Statistical Simulation Methodology

In systems engineering, physical simulators are used to describe relationships between the system's design and the manufacturing processes in terms of the system's design characteristics. The goal is to permit the system to be designed and manufactured correctly and efficiently. Effects of uncontrollable variation in manufacturing and operational parameters can, however, lead to variations in the end result. For instance, it may be that the system characteristics are inordinately sensitive to slight variations in the manufacturing process consequently resulting in potential reduction in yield or percentage of marketable systems produced. Obviously, understanding and controlling the sensitivity of a system's characteristics can be critical to the concept of flexible quick turn around systems design while allowing more reliable systems and increasing the overall quality of the system. [1]

Monte Carlo techniques have often been used to provide simple approaches to the statistical simulation of engineering problems [2]. However while Monte Carlo based methods have the theoretical capability for statistical accuracy, they suffer from a number of real-world difficulties. Large numbers of simulation runs are required to obtain any reasonable degree of statistical accuracy. Furthermore, Monte Carlo approaches do not provide other critical engineering and manufacturing information such as how the system response varies as a function of input variables, or how to optimize this response.

Design of Experiments (DoE) is an alternate statistical optimization methodology long used in process development [3]. It provides a systematic way of characterizing the variabilities of a process while minimizing the number of replications needed to do so. However, this statistical methodology has not been used in design of flexible manufacturing processes for several reasons. The primary reason is that it has usually been laborious and practiced only by experienced statisticians. Although design of experiments can be used to estimate very useful statistical parameters such as the mean and standard deviation of the output response, it does involve complex but straight forward mathematical manipulations that can best only be applied by computer. Recently, Design of Experiments has been used to accomplish statistical simulations of integrated circuit process development [4,5]. Our solution thus involves the development of a computer program to guide system design engineers through this complex mathematical sequence toward system optimization.

Another reason why design of experiments methodology is not typically used to full advantage in system engineering optimizations involves the practical difficulties encountered with simulators. Most simulators require the user to possess in depth knowledge of both the manufacturing processes and the specific workings of the simulator packages themselves. Our solution to this problem involves a user-friendly input system where a user easily enters the specifics of the system to be manufactured. The simulations are then automatically set up and run with software selection of proper input

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variations as dictated by the embedded design of experiments theory.

**STADIUM**

The software program being discussed in this paper is called STADIUM and was originally conceived and developed at Florida Institute of Technology. The major functional blocks of STADIUM are shown in Figure 1 which also shows how they form an integrated capability. STADIUM can employ almost any valid simulator of interest and achieve correct statistical predictions of the results of the manufacturing operations[6,7].

STADIUM is primarily employed in predicting the variation of system level parameters due to expected incidental variations encountered during the phases of manufacturing and use. The statistical design of experiments methodology is typically accomplished using an internal customized statistical package. In each case, it is automatically accomplished in conjunction with relevant component, subsystem and system level simulators to allow the proper design of the statistical experiment,

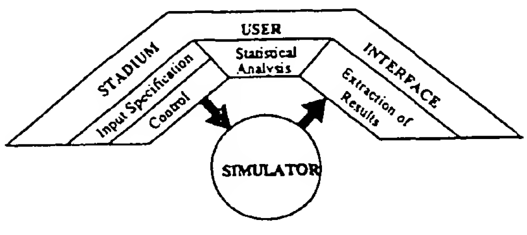


**Figure 1: The STADIUM Conceptual Architecture**

This statistical experiment is then automatically run using component, subsystem and system level simulators relevant to the problem at hand. The result of this computer designed statistical experiment is analyzed under user supervision to provide the precise statistical description of system performance as a function of those manufacturing parameters found to be of significance. These analyzed statistical results can now be reliably used by system engineers as an aid in optimizing system performance and quality, reducing manufacturing costs and making life-cycle trade-offs.

STADIUM utilizes a graphical menu driven X-window user interface to allow for specification of known manufacturing variables and operation parameters. These processes are independent of the simulators to be employed and thus the system engineer does not need to be overly familiar with the interface characteristics of the variety of simulators themselves. STADIUM then uses this data via automated design of experiments techniques to conduct a batch run of simulations - the results of which are automatically analyzed for performance prediction. The software architecture of the STADIUM package facilitates the ready integration of alternate simulators from a variety of vendors. Thus STADIUM also lends itself to the flexible system engineering design concept by itself being readily readapted to newly emerging variations of the system and manufacturing process.

**Application to System Optimization**

Some of the worlds most complex and costly electronics products have been developed for the military. Now in a different time, the emphasis is swinging to rapid flexible design and manufacture of systems on demand. This is of course layered onto the already difficult problems of developing extremely complex and sophisticated systems. Earlier approaches toward handling the design complexity of the system, i.e. a methodology of systems engineering centering around a series of checks and balances of technical specification, is now inadequate for the future. In yesterday's system engineering, concepts of statistical manufacturing variability, while understood, were for the most part ignored in the drive for technical excellence. Now, escalating system costs and reduced budgets lead to the serious consideration of flexible system optimization to the task at hand on demand. These needs have become increasingly serious in the already current environment of defense conversion and dual-use technology. Consequently, we present here an example of how the STADIUM statistical methodology can now form a critical component within the domain of system optimization.

Large complex systems are usually subject to a variety of requirement demands including those of technical performance, usability and reliability. This has led to the development of specialized system design simulators. In contradiction to other simulators, system design simulators do not simply predict physical parameters. They are typically more geared to satisfaction of tasking; i.e., how well can insertion of a system into a larger and enveloping environment improve the overall tasking. Thus system simulators must simulate portions of the tasking environment as well as that of the system under design. They are however not generally responsive to determining the impact of variabilities within the manufacturing environment.

In the area of night vision system design, the FLIR90/ ACQUIRE [8] (and subsequent FLIR 92/ACQUIRE) simulator is the standard in task oriented FLIR system simulation. It uses a simulated "standard" human observer and a rigorous FLIR system simulation to allow design trade-offs within an overall FLIR tasking. FLIR systems developed to the component specifications satisfying the FLIR90/ACQUIRE simulation will be generally accepted by a customer without need for conventional field trials.

A particular difficulty with the use of system design simulators, such as FLIR90/ACQUIRE, is that they do not recognize the existence of the physical variability in systems components encountered in the manufacturing process. Rather, such simulators assume that every component has zero variability. However, ignoring the possibility of component variability in manufacturing leads to worst- case component design and resulting cost escalation. This is specially true in the case of flexible design and manufacturing runs where there is no time for use of a "learning curve" approach toward redesign for improved performance.

Introducing statistical manufacturing methodology into the system's design simulation can greatly reduce the potential waste of manufacturing resources. STADIUM inherently recognizes that all components have natural variability and are not the "idealized" precision components typically assumed in design. It also recognizes that these natural variabilities feed through the system design in varying degrees thus affecting the performance of the final manufactured system. Finally, STADIUM greatly aids the process of nominal design value versus manufacturing variability trades by reducing requirements for precision components.

In general, STADIUM makes full use of existing design simulators to avoid developing and revalidating statistical versions of existing system design simulators - a process that can be costly in terms of time and schedule. For instance, the FLIR90/ACQUIRE system design simulator was simply incorporated intact into STADIUM. Since the underlying simulator was not changed, there was also no need for any revalidations. The resulting statistical FLIR manufacturability simulation package is called STADIUM/FLIR90. Its top level user interface is shown below as figure 2.

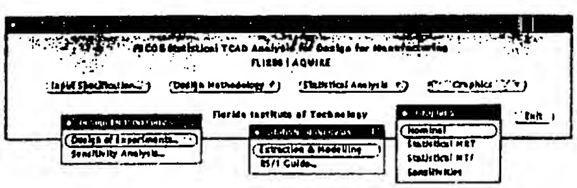

Figure 2: The Top Level User Interface

When the engineer completes an Input Specification, the Input Specification window appears as shown in Figure 3. This Input window, provides the manufacturing engineer

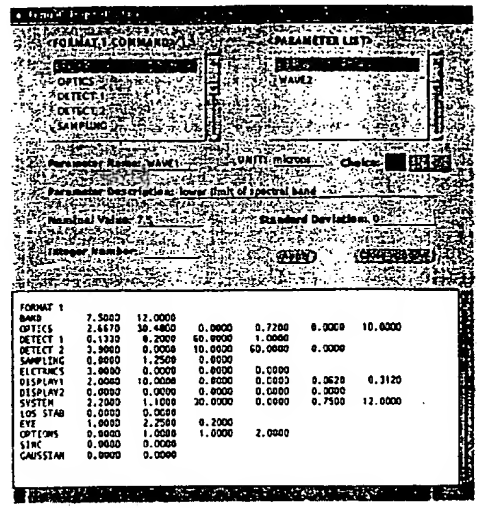

Figure 3: A FLIR Parameter Input Window

with a simplified and interactive workstation display which is a great usability improvement over the conventional batch card deck input of FLIR90/ACQUIRE. It also permits the engineer to interactively specify expected standard manufacturing deviations of individual parameters in addition to their customary nominal design values.

The Design Methodology window of STADIUM/FLIR90, allows a non-statistician manufacturing engineer to straightforwardly set up manufacturing Design of Experiment analyses. This sets into motion a statistical manufacturability simulation outputting statistically consistent system wide results stemming from the manufacturing variabilities introduced in the Input Specification window. Alternately, STADIUM allows the system engineer to conduct "what if" manufacturability sensitivity optimization experiments against specific series of variations.

From the Design Methodology window, STADIUM automatically conducts the specified statistical experiment in an execution-efficient manner using the FLIR90/ACQUIRE simulator.

Through the Statistical Analysis window, the system engineer is given a statistical analysis of system performance. To accomplish this analysis, STADIUM has the capability of either using an internal analysis package or if preferred an alternate drop-in third-party statistical analysis package such as RS/ 1. The output is presented as a numerical display of nominal system level results (similar to the fixed output of the previous non-statistical system design runs of the stand-along FLIR90/ ACQUIRE simulator), as well as their standard

deviations. STADIUM also provides the output percentage contribution contributed by each input component's manufacturing variation, and finally a mathematical model of the statistical manufacturing process.

Because manufacturing engineering is multi-disciplined and sophisticated, STADIUM also provides a highly useful graphical results plotting capability. The Graphics plotting window of Figure 4 provides for four classes of graphics plotting of results, with at least 100 variations. These graphics can be shown at the workstation and/or exported for presentation quality hardcopy.

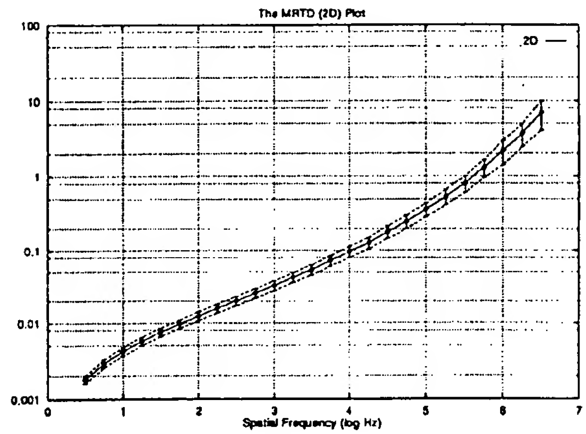


**Figure 4: Statistical MRTD Results Curve**

For instance, Figure 4 shows a typical plot of the statistical manufacturability of the FLIR system's MRTD(Minimal Resolvable Temperature Difference). The variability bars show the one standard deviation variability at user selected critical points.

The dotted variability envelopes show the expected variability over the entire MRTD range and may be used to insure that the entire manufacturing run will meet customer dictated system specifications.

## Conclusions

A software program called STADIUM has been recently developed at Florida Institute of Technology to addresses the design issues engendered during system optimization against statistical variabilities. Specifically, STADIUM is used to predict the high-level variations of component and system level parameters due to the low-level variations of manufacturing and operational processes. STADIUM accomplishes this by setting up a statistically relevant design of experiment in conjunction with industry-standard component and system level simulators. Next, this statistical experiment is automatically run by STADIUM using the appropriate component and system level simulators. STADIUM then analyzes the results of the experiment under user control to provide a precise statistical description of component and systems performances as a function of manufacturing parameter variabilities. These statistical performance statements can then be reliable used by design engineers in optimizing component performance, reducing manufacturing costs and making life-cycle trade-off.

The following are some of the key characteristics of STADIUM that makes it so relevant to the realm of rapid turn around system design. Its X-window user interface allows simple and rapid specification of current manufacturing variables and operational parameters as well as their variabilities. Then using appropriate preexisting industry simulators and its own automated design of experiments, STADIUM automatically runs the minimum number of simulations required to predict overall statistical performance. Thus STADIUM rapidly adapts to the ever changing conditions of specific flexible system optimization frameworks due to its acceptance of statistical rather than hard knowledge of manufacturing variabilities, and its rapid turn around execution times.

STADIUM has customarily been used for statistical simulation of CMOS and Bipolar semiconductor manufacturing processes. With support from Texas Instruments, STADIUM has also begun to allow statistical analyses of sophisticated FLIR imagery sensor systems. Here STADIUM is capable of tracking global FLIR sensor performance as a user selectable function of over fifty manufacturing variables. Currently, STADIUM is being intermeshed with a Design Advisor program under a DARPA contract with Florida Tech as a subcontractor to Texas Instruments. The resulting "STADIUM/MADE" integrated system design analysis/statistical optimization tool will possess a coherent system wide ability to capture, synthesize, analyze, and model complex system designs subjected to a wide spectrum of statistical concerns, including those resulting from flexible manufacturing and operational use.

Much of the expanding success of the STADIUM package arises from its straightforward ability to integrate off the shelf simulators from a variety of vendors. This has been an essential key allowing its rapid transition from semiconductor to image sensor domain for instance. Such changes only require making minor changes to the Input Specification, Data Selection and Graphic Display window functions of STADIUM. In the past, this has been done by reprogramming within STADIUM, but a goal of the MADE effort is to allow the user him or herself to more easily insert new simulators. This of course will greatly facilitate the rapidity with which flexible system optimization functions can be readjusted to changing market considerations.

## References


1. "Improving Engineering Design - Designing for Competitive Advantage", *Committee on Engineering Design Theory and Methodology,* National Research Council, National Academy Press, 1991.

2. William J. McCalla, *Fundamentals of Computer Aided Circuit Simulation*", Kluwer Academic Publishers, 1988.

3. S.R. Schmidt and R.G. Launsby, *Understanding Industrial Designed Experiments,* Air Academy Press, Colorado Springs, CO 1992.

4. T.J. Sanders, K Rekab, D.P. Means and F.M. Rotella, "Integrated Circuits Design for Manufacturing through Statistical Simulation of Process Steps", *IEEE Transactions on Semiconductor Manufacturing,* November, 1992.

5. T.J. Sanders, K. Rekab, D.P. Means and F.M. Rotella, "Statistical Design Methodology for Integrated Circuit Technologies", *Government Microcircuit Application Conference Digest of Papers, Volume XVIII,* pp. 441-444, November, 1992.

6. T.J. Sanders, M.M. Shahsavari, D.P. Means, K. Moye, and S. Chung, "Statistical Design for IC Processes, Devices and Circuits", *Government Microcircuit Application Conference Digest of Papers,* Volume *XVII,* November, 1991.

# System level optimization through the use of statistical simulation

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Index Terms

**Inspec**

**Controlled Indexing**

design of experiments digital simulation flexible manufacturing systems manufacturing processes optimisation statistical analysis systems engineering

**Non-controlled Indexing**

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